Vibration Monitoring of Rotating Machines
Applications in Thermal Power Plants

Need for Vibration Monitoring

Many new supercritical power plants are coming up in India. Maintenance and instrumentation. At the same time, a large number of old power plants in the country need to be upgraded to avoid frequent shut down for maintenance. Maintenance and instrumentation engineers are facing several challenges to maintain a high uptime.

Understanding machine health and planning actions in advance can increase plant uptime to 95%. Monitoring of critical machines is key to increasing efficiency and reliability and prevent frequent failures. Real time vibration monitoring helps prevent frequent failures.

Causes for Vibrations

Vibration can be due to several reasons such as

- Unbalance of shaft
- Bearing problem
- Cracking of the rings
- Fluid coupling problem
- Shaft misalignment
- Oil whirl and other dynamic instabilities

These problems can gradually become very severe and result in unplanned shut downs. To avoid plants have a Time Based Maintenance (TBM) or preventive maintenance system. One can extend the life of the machines by monitoring these online in a cost effective way. Vibration monitoring and analysis is the easiest way to keep machines healthy and efficient in the long run and increase the overall efficiency of the plant. It reduces the overall operating cost as well as the down time period. Vibration sensors are used to predict faults in a running machine without dismantling it and give a clear indication of the severity by showing the amplitude of vibration.
Typical Applications in a Power Plant

The figure below indicates all critical machines where vibration monitoring is recommended to prevent shut down.

Philosophy of Machine Condition Monitoring

In power plants rotating machines are divided according to their criticality into three categories as shown in the adjacent triangle.

First critical machine – Turbine and generator

Secondary critical machines – ID fan, FD fan, PA fan, boiler feed pump, cooling water pump, condensate extraction pump, critical large HT motors of mills.

Balance of plant machines - Coal handling plant crushers, cooling tower fans, raw water pumps and make up water pumps.
This solution is cost effective as maintenance can be planned without compromising the total availability of the plant. Condition characteristics of the machine such as bearing damage, unbalance, alignment or cavitations enable a differentiated evaluation of mechanical stress which will keep all on track for when to have the shut down and the process is ongoing without any manual interruption. Hence we will be able to protect the equipment from expensive consequential costs.

Implementing predictive maintenance leads to a substantial increase in productivity (up to 35%). However, the need can be determined only after understanding the health of the machine without dismantling it. This is possible only by online monitoring. Knowledge of the root cause of the malfunctioning of the machine can help expedite the actions that are needed to be taken instead of shutting down the whole system. This is nothing but predictive maintenance for prediction of the health of the machine. Here the performance level is decided with the help of the reports taken at intervals. There is rapid notification and fast error detection. Diagnostics feature give the root cause of the failure of machinery.

### Turbine and Generators

Turbines are the most critical equipment in a power plant. The main turbine is the heart of the power plant. It is mandatory to use maximum protection as well as on line measurements of different parameters to avoid any unexpected failure and shutdown. In TSI there are almost 10 to 12 parameters to be measured. This requires Turbo Supervisory Instrumentation of more than 36 online sensors and monitors and analysis/diagnosis system. To keep the main turbine running efficiently, it is recommended to continuously monitor some second level critical machines.

### Major Measurement Categories for TSI

**Motion:** Shaft vibration, eccentricity, phase, speed measurement

**Position:** Thrust, rotor position, case expansion, differential expansion, valve position

**Process parameters:** Temperature, pressure, flow
Vibration Measurement Parameters

Radial Vibration

Radial vibration measures the radial motion of the rotating shaft relative to the case. This measurement gives the first indication of a fault, such as unbalance, misalignment, cracked shaft, oil whirl or other dynamic instabilities. Vibration Measurements can be made in a single plane or a two plane (X-Y) arrangement where the sensors are 90 degrees apart and perpendicular to the shaft.

Eddy current probes are usually installed in a hole drilled through the bearing cap and is held in place by either a bracket or a probe holder.

Absolute Shaft Vibration

Absolute shaft vibration is a measure of the shaft’s motion relative to free space. The measurement is typically applied when the rotating assembly is five or more times heavier than the case of the machine. Absolute shaft motion is proportional to the vector addition of the casing absolute motion and the shaft relative motion.

Casing Vibration (Absolute Bearing Vibration)

This is the vibration measurement to measure vibration on bearing housing by using contact type sensors mounted with the help of mounting pad / studs. These are mounted 90 degree apart from each other. Typically piezovelocity and accelerometer sensors are used.

Casing Expansion

Steam temperature varies greatly between startup, operation, and shutdown. Shell expansion is a measurement of how much the turbine’s case expands from its fixed point outward as it is heated. Continuous indication of shell thermal growth allows the operator to manage the amount of shell distortion as the load is increased or decreased. This thermal growth of the case from its fixed point outward is measured by the Linear Variable Differential Transformer (LVDT) plunger fixed to the case.
**Differential Expansion**

Differential Expansion (DE) is the difference between the thermal growth of the rotor compared to the case. It provides the operator continuous indication of the critical clearances between the expanding rotor and blades with respect to the expanding shell or casing. Differential expansion monitoring is critical during a turbine "cold" start-up. The rotor is fixed axially by the thrust bearing. This thrust bearing moves as the case expands - thus the need to monitor the difference in thermal expansion. Ideally, differential expansion should indicate zero change in the gap relationship between the two surfaces.

**Thrust Position (Axial Measurement)**

Axial position (thrust) is a measurement of the relative position of the thrust collar to the thrust bearing. Measurement may be made in both the active and inactive thrust directions. Measurements taken outside of the thrust bearing area (greater than 12 inches) are generally affected by the rotor's thermal expansion and an increase in the required dynamic measurement range. This measurement is typically referred to as rotor (axial) position.

**Eccentricity Measurement**

Eccentricity is a measurement of the amount of sag or bow in a rotor. After an extended shutdown, the shaft will bow if heated unevenly. Prior to startup, the rotor is placed on turning gear and slow-rolled, allowing the shaft to straighten to within acceptable limits - the turbine is not brought up to speed until eccentricity is within limits. Excessive eccentricity could cause rubs and damage to the seals. Eccentricity measurement may also provide indication of a bent shaft.

**Phase Measurement**

Phase is defined as the angle between a reference mark (usually a keyway on the shaft) and the heavy spot on the rotor. Phase measurement is required for accurate balancing of any rotor. It also provides an indication of shaft cracks, misalignment, mass loss (such as throwing a blade), and other faults.
Large Fans with HT Motors

Other critical machines in power plants are fans used for ventilation and industrial process requirements. Induced Draft Fans (ID Fans) and Forced Draft Fans (FD Fans) are used to control air flow through the stack, maximizing the efficiency of the boiler.

Gas Recirculation Fans collect unburned gas and send it back to be burned again, reducing the particulates that are emitted to the air. As in vibration terms fans contributes to the maximum. The motor shaft is coupled to the fan through the coupling (plume block), can be fluid coupling.

- Induced Draft Fans (ID)
- Forced Draft Fans (FD)
- Primary Air Fans (PA)

Vibration Monitoring System in Power Plants

Sensors

There are three principal vibration sensors as

- **Displacement transducer**
  - An eddy current device

- **Piezo velocity transducer**
  - A spring held magnet moving through a coil of wire

- **Accelerometer**
  - A piezoelectric device somewhat similar to ultrasonic transducers

Non-Contact type displacement sensors (eddy current)

Non-contact devices measuring the gap between the plant equipment and the fixed sensor. It is usually mounted 380-2,030 µm (15-80 milli-in.) from the part to be observed. The coil in the eddy current device is usually a pancake coil in the end of a cylindrical tube that can be mounted close to the moving part. Excitation is very high frequency, about 240,000 Hz, for detection of small gap changes (as low as 1 µm i.e. 40 milli-in.) at 0.5 MHz. This sensor measures vibration as horizontal or vertical motion (requiring two different mountings of one sensor or two sensors). The best measurements are at low frequencies of vibration of the part, below 1,000 Hz, where signals as large as 4,000 mV/µm (100 mV/milli-in.) can be obtained. Since the signal can be large, very low amplitude displacements or vibrations can be measured. Displacement sensors work well for applications such as shaft motion and clearance measurements.

Piezo Velocity Sensors

These are usually spring held magnets moving through a coil of wire, suitable for a wide range of frequencies (1 to 20,000 Hz). They work best for high frequencies where acceleration is large. Examples are the passage of turbine blades, which may be one hundred times the shaft rotation, or the meshing of gears or ball/roller bearings, which may be many times the shaft rotations per minute. Other advantages include their small size, lightweight, good temperature stability, and moderate price.

Accelerometers

These are piezoelectric devices somewhat similar to ultrasonic transducers. They develop a voltage from a piezoelectric crystal that has a mass mounted upon it. A quartz crystal is frequently used. When the mass fixed to the crystal vibrates from the motion of the device upon which the sensor is attached, the crystal generates a voltage proportional to the force applied by the mass as it vibrates with the machinery. While no external excitation is required for the sensor to produce its voltage signal, the signal is small (self-generated) and requires a preamplifier. The preamp is often in the sensor case so the connecting cable must carry preamp power to the sensor as well as the signal from it. The accelerometer is the workhorse of vibration sensors because they offer such a wide range of working frequencies plus the other advantages given above.
API-670 Monitoring System

For plant maintenance, having API670 compliant vibration sensors, 19” rack based monitoring system and required relay outputs, 4-20mA outputs, DCS interface and 02 raw buffer signal output is beneficial.

API-670 brings all suppliers on the same platform. It is now possible to replace sensors and monitors with other makes during maintenance.

It is a good practice to follow API 670 design standard for turbine and other applicable BOP machines in the power plant to avoid issues later on.

Requirements of API 670 Standard

19”-rack based system with mother board
Redundant power supply in the rack
Maximum 44 channels in one rack
15 Key phasor in one rack
Relay output for each channel
LCD display unit
Each module should be 2 Ch / 4 channel maximum
Redundant ethernet output to DCS
Hot swappable cards
Minimum variety of modules
Configurable at field
Standard protocol with real time monitoring
High reliability
Lead free technology is preferred
No hardwiring
Analysis output from each rack for further integration (must be transient and steady state)
BNC connectors on front and rear of monitors
Front LED status on each monitor

Multichannel monitor (Condition Monitoring System of large rotating machines like turbines, compressors, BOP machines)

Dual channel monitor with integrated display for all rotating machinery, from large to small i.e. captive turbines, pumps, motors, etc.
Transducer System

**FK Series Displacement Eddy Current Transducers**

The FK-202F transducer is the eddy current type non-contact displacement/vibration transducer, used for measuring shaft vibration, axial position, rotating speed and phase mark (phase reference) from small rotating machinery to large critical machinery such as turbines and compressors in plants. In addition, the FK-202F is designed to meet the API (American Petroleum Institute) standard 670 (5th Edition) requirements, often referred by the machinery protection systems for the petroleum refinery and the petrochemical plant in world wide.

Suitable for various applications: shaft vibration, axial position, rotating speed and phase mark of the critical rotating machinery.

Environmental friendly design: lad-free soldering, RoHS directive compliant and downsized.

Wide variety of driver mounting: DIN-rail adaptor, 4-screw cramp plate adaptor (to replace VK series and others)

API standard 670 (4th Edition) compliant

Intrinsically Safe: TIIS, CSA, ATEX, NEPSI, KTL

CE directive compliant

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**CA/CV Series Velocity Sensor and Accelerometers**

Multi-purpose and intrinsically safe accelerometers. Available in both top and side connectors, or with top and side exit integral cables.

High temperature, low frequency and piezo velocity transducers

Available in both top and side connector versions

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**Machinery Protection / Monitoring System**

**VM-7B Series – Simple, highly functioning and consistent performance - four channel API 670 Std. Monitoring System**

The VM-7B series monitor is designed according to ISO international standards and the API standards, and has the functions and features of the machine condition monitor, is used for machines in plant, and is used for the machine protection system defined in the API standard 670 in particular.

**Features**

Redundant power supplies.

True redundant communication to DCS / PLC

Isolated 4-20 mA output

Single monitor module (VM 701B) for 7 parameters

Inbuilt analysis function in each module (optional)

Inbuilt relay in each module

Fully programmable relay in the rack for any configuration and logic

Raw signal output – front BNC and rear terminals

API 670 compliant

24 Bit microprocessor

Lead free soldering – caring environment

44 Input channel in each rack
### System Configuration VM-7 B

![Diagram of the system configuration](image)

#### Monitor Modules and Monitoring Parameters

<table>
<thead>
<tr>
<th>Monitor Module</th>
<th>Monitoring Parameter of Inputs</th>
<th>Number of Outputs</th>
<th>Number</th>
<th>Input Transducer</th>
</tr>
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<tbody>
<tr>
<td>VM-701 B Vibration / displacement monitor module</td>
<td>Displacement vibration</td>
<td>4</td>
<td>4</td>
<td>FK</td>
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<td>Velocity vibration</td>
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<td>CA</td>
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<td>Thrust position</td>
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<td>FK</td>
</tr>
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<td></td>
<td>Differential expansion (single input)</td>
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<td>4</td>
<td>FK</td>
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<tr>
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<td>Ramp differential expansion</td>
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<td></td>
<td>Complementary input differential expansion</td>
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<td>2</td>
<td>FK</td>
</tr>
<tr>
<td></td>
<td>Case expansion complementary expansion</td>
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<td>3</td>
<td>FK &amp; LS + VM-21</td>
</tr>
<tr>
<td></td>
<td>Case expansion</td>
<td>4</td>
<td>4</td>
<td>LS + VM-21</td>
</tr>
<tr>
<td></td>
<td>Valve position</td>
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<td>4</td>
<td>LS + VM-21</td>
</tr>
<tr>
<td>VN-702 B Absolute vibration monitor module</td>
<td>Shaft relative vibration and shaft absolute vibration or casting vibration</td>
<td>4</td>
<td>4</td>
<td>FK &amp; CV (for 2CH)</td>
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<tr>
<td>VM-703 B Tachometer and eccentricity monitor module</td>
<td>CH1 Rotor speed</td>
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<td>2</td>
<td>FK, RD or MS</td>
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<tr>
<td></td>
<td>CH2 Rotor acceleration</td>
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<td>1</td>
<td>Rotor speed of CH1</td>
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<tr>
<td></td>
<td>CH3 Eccentricity</td>
<td>1</td>
<td>2</td>
<td>FK &amp; Ø</td>
</tr>
<tr>
<td>VM-704 B Temperature monitor module</td>
<td>Temperature</td>
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<td>6</td>
<td>TC or RTD</td>
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<td>VM-706 B Rod drop monitor module</td>
<td>Rod drop</td>
<td>4</td>
<td>4</td>
<td>FK &amp; RD</td>
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</tbody>
</table>
VM-25 Digital BOP Monitor

VM-25 monitoring system is designed with IoT in-mind, contains features and functions required for BOP (Balance of plant) monitoring. VM-25 can be customized to suit end user needs, and its compact design means it fits almost anywhere.

Features
- Digital communication – Modbus/TCP communication with IoT system via single Ethernet cable
- Right-sized – available in 4, 6 and 8 channel monitoring arrangements along with up to 4 recorder outputs and up to 8 relay outputs, and
- An optimized design – enables installation in small spaces along with multiple mounting arrangements. Dimensions, 120 x 160 x 100mm.

Functions
- Standard vibration measurement (velocity, acceleration transducers)
- Modbus / TCP communication
- A 7 digit LED front-facing display
- Recorder output (non-isolated)
- Optional recorder output (isolated)
- Relay output
- Dedicated configuration software enables operators to change monitor settings

Example System Configuration

Analysis Hardware for Software Integration (Daqpod)

This is a real time processor for steady state and transient measurements from monitor racks via raw signals for analysis and diagnostics purpose. Output from these units will be ether net and connected to software. Monitoring system (as per API 670 Std) has sensor signal output either on monitor front BNC or rear terminals. This signal will be connected with a multipair cable to the Shinkawa terminal box which will convert this into D connector output. This D Connector output will be then be connected to the Shinkawa analysing processor which will process this signal and give high speed analysis data output in form of ethernet TCP IP. This output will be then connected to a server where RV200 analysis software will be loaded and further processing and GUI plots will be made as an expert analysis and diagnosis system.
Machinery Management Analysis and Diagnostic System infiSYS RV200 Series

The complete vibration analysis and diagnostic system. With the latest analysis technology, online vibration analysis systems are capable of analyzing and managing, all sorts of data essential for large rotating machinery, on personal computers. The software based on WindowsNT® platform allows easy operation and various analysis functions. InfSYS RV200 has analysis view software that takes data out from the analysis module VM-742B and displays the same. It displays the set value, measurements, and the status of the analysis module and the analytical data.

API 670 - 19” Rack Based Monitoring with Analysis and Diagnosis System

Analysis Software Features
Machine train diagram (24 machine train diagrams or less can be registered)
Current value summary
Trend graph: overall, GAP, 0.5X amp. / phase, 1X amp. / phase, 2X amp. / phase, Not 1X amp., and RPM
Bar graph: overall, 0.5X, 1X, 2X, Not 1X
Other graphs
Waveform / spectrum
Lissajous, lissajous and waveform, vector plot
Orbit, S-V graph, X-Y graph.
Transient trend, transient waveform / spectrum.
Transient lissajous, transient lissajous and waveform
Transient polar plot, transient (bode diagram), transient orbit
Trend during alarm, waveform / spectrum during alarm, system history, alarm history

InfiSYS RV200 has diagnosis software that gives the health of the rotating machinery i.e. displays the reason of the internal faults caused.

Diagnosis Software Features
A malfunction cause is displayed in order from the high thing of the factor as a result of diagnosis.
Diagnosis possible malfunction causes: unbalance, permanent bow, lost rotor parts, misalignment, critical speed, rotor crack, non symmetrical rotor, gear inaccuracy, seal rub, oil whirl, oil whip, steam whirl / seal whirl, cavitations, wing vibration, draft core, surging.
Vibration Consultancy Services Agreement (VCSA)

Proactive Care for Critical Rotating Machines
Imagine if you could monitor the health problems of critical rotating machines – even before the symptoms become evident

A Forbes Marshall specialist will be promptly available at your doorstep to address the problem

The Consultancy Services Agreement (CSA) is a suite of proactive asset care services tailored to your individual needs and designed to help you harness the full potential of the installed condition monitoring systems

Our Expertise
Survey of rotating machines in your plants
Possible suggestions for vibration monitoring requirements
Vibration consultancy support for giving reports monthly / quarterly for critical machines and secondary critical machines
Right proposal to optimise the on line monitoring cost
Complete turnkey execution, engineering and documentation
Vibration analysis and diagnosis reporting for the right time to shut down to save cost. Customised condition monitoring and reporting plan for your plant.

Specialists Available On Call
When there is a problem, we can perform diagnostics and give you advice on the cause and how to fix it. We can provide this service, quarterly, monthly or on-demand.

Personalised Solutions for Individual Needs
With a complete knowhow of on-line vibration monitoring systems and machine details, we have developed the Vibration Consultancy, a unique service for customers in all types of industries. Through this service, we offer our clients remote vibration analysis and give reports for every critical rotating machine in the plant, by either remote monitoring of critical machines 24 X 7 and/ or periodic measurements by visits to the plant for other critical machines such as large pumps, ID/FD/PA fans, centrifuges, large blowers, gear boxes, motors, crushers, compressors and other rotating machines.

Implementing predictive maintenance leads to a substantial increase in productivity (upto 35%), on the one hand preventing unpredicted shutdowns, while on the other, anticipating corrective operations so that they can be carried out under the best conditions.
Condition Monitoring and Assessment of Rotating Machinery through Remote Vibration Monitoring System (RVMS)

Analysis and Diagnostic Software, RV200

Internet

H.O. Expert

Remote Monitoring Station by Laptop / Mobile

Analysis Hardware AP2000

O&M Expert

19" Rack based VMS for boiler

Analysis Output

TSI Rack

Transformer

Steam Turbine

Generator

Cooling Tower

AHP

CHP

19" Rack based VMS for boiler

Buffer Output

VM-25 Monitor for BOP

MON-1

MON-2

MON-3

MON-4

MON-1

MON-2

MON-3

MON-4

PUL 12

PUL 12

PUL 12

Cooling Tower

Boiler (IDF/FDF/PAF/MILL/CEP)

Electrostatic Filter

Condenser

BFP/CWP

Transformer

Generator

Cooling Tower

AHP

CHP

19" Rack based VMS for boiler

Buffer Output

VM-25 Monitor for BOP

MON-1

MON-2

MON-3

MON-4

PUL 12

PUL 12

PUL 12

Cooling Tower

Boiler (IDF/FDF/PAF/MILL/CEP)

Electrostatic Filter

Condenser

BFP/CWP
Need for 24X7 Vibration Monitoring for Machines

Currently, in many plants, the technical know-how of vibration monitoring is limited, which calls for specialised support and timely guidance to avoid an emergency shutdown.

Forbes Marshall provides the solution for advanced remote vibration monitoring through the analysis software.

All the data related to vibration and process values of the machines are captured 24x7 at intervals as required by the user. Data is available whenever required. This will give the information of when the alarm had occurred, what was the fault i.e. abnormality in the machine.

Benefits of this Concept

Remote monitoring through analysis software is effective for old and new power plants – from 1MW to 1000MW.

User can monitor and analyse the vibration of his rotating machinery very well, which will result in better maintenance of the machinery.

Dynamics of machinery like critical speeds, behavior of machinery in transient conditions like startup and shutdown will be better understood to pin point any abnormal condition.

Analysis and display functions i.e. machine trains, trend graph, spectrum, shaft center line position, bode/polar plot, orbit display, vector plot, alarm status, etc. The user can prevent any possible failures by taking corrective action.

This will eventually increase equipment availability and reliability and reduce costs.

Internet explorer via web connectivity can be used to see details anywhere globally on any PC or mobile.

It is used on any machine for any vibration analysis function need.

It gives advance information to customers on machine issues to avoid shut down. Experts use know how of multiple plants to guide plant O&M teams.
Vibration Monitoring Solutions for Secondary Rotary Machines

ID / FD / PA fans, CEP / CWP / ACWP / BFP pumps and mill motors, coal handling plant crushers, RWP, MWP and cooling tower (IDCT)

**Option 1:** API 670 - 19" Rack Based Monitoring with Analysis and Diagnosis System
For complete plant – turbine and other machines together and interface to any old supplied system

Software installed:
infiSYS Analysis View VM-773B
infiSYS View Station
infiSYS Remote Station

Ethernet

DAQpod AP-2000
VM-5 or other Commercial Monitor

Software installed:
infiSYS Remote View VM-774B

VM-7B
Redundant DCS Comm

Buffered Signals

Field junction box (ATEX)

**Option 2:** Non API 670 19" Rack Based System with Analysis and Diagnosis System.

Software installed:
infiSYS Analysis View VM-773B

infiSYS View Station
infiSYS Remote Station

Ethernet

DAQpod DP-2000

VM-25 or other commercial monitor

Software installed:
infiSYS Remote View VM-774B

VM-7B
Redundant DCS Comm

Buffered Signals

Field junction box (ATEX)
**Recommendations**

We recommend the complete TSI System as per TG OEMs have a vibration monitoring system designed as per API 670. It should be globally proven and should have good service network and support.

For pumps, fans and motors we recommend 8 piezo velocity sensors and 1 phase marker for horizontal machines having single speed and 02 phase markers for 02 speed machines. This system also should be as per API 670 design to avoid any issues later on.

A machine tripping must be taken from a reliable API 670 design machine.

As far as possible there must be:
- Sensors up to JB must be kept in rotating machine OEM scope
- Monitoring system with complete integration with owner or large EPC
- Supplier should have a proven track record in India for more than 2-3 years for service support in more than 10 sets of power plants. There should be a service network across India and globally.

**Conclusion**

By monitoring the performance of the critical machines and secondary critical machines we can schedule predictive shutdown of the plant instead of frequent unplanned shutdowns

The root causes of machinery failure can be known by using vibration monitoring systems

Lead to increase in the reliability of the system machinery

Reduction of manual intervention that could be erroneous

Monitoring will eventually increase the plant uptime to 95% overall